

# Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms

Completed Technology Project (2014 - 2015)



## Project Introduction

Kennedy Space Center has teamed up with the Biological Computation Lab at the University of New Mexico to create a swarm of small, low-cost, autonomous robots, called Swarmies, to be used as a ground-based research platform for in-situ resource utilization missions. The behavior of the robot swarm mimics the central-place foraging strategy of ants to find and collect resources in an unknown environment and return those resources to a central site. The swarm has no prior knowledge of the environment, uses trails as a simple indirect communication strategy, and evolves a set of behavioral parameters using a genetic algorithm. The evolution of the parameters allows the swarm to maximize collection rates while adapting to new environmental conditions and to various unknown resource distributions. The goal of this research is to add new in-situ resource utilization related behaviors to the genetic algorithm and to increase the autonomy of the system.

As humans push further beyond the grasp of earth, robotic missions in advance of human missions will play an increasingly important role. These robotic systems will find and collect valuable resources as part of an in-situ resource utilization strategy. They will need to be highly autonomous while maintaining high task performance levels.

Kennedy Space Center has teamed up with the Biological Computation Lab at the University of New Mexico to create a swarm of small, low-cost, autonomous robots, called Swarmies, to be used as a ground-based research platform for in-situ resource utilization missions. The behavior of the robot swarm mimics the central-place foraging strategy of ants to find and collect resources in an unknown environment and return those resources to a central site. The swarm has no prior knowledge of the environment, uses trails as a simple indirect communication strategy, and evolves a set of behavioral parameters using a genetic algorithm. The evolution of the parameters allows the swarm to maximize collection rates while adapting to new environmental conditions and to various unknown resource distributions.

The goal of this research is to add new in-situ resource utilization related behaviors to the genetic algorithm and to increase the autonomy of the system. Digital trails that are based on ant pheromone trails provide simple communication of resource locations between robots but they also provide some assistance with obstacle avoidance and navigation. Two newly evolved genetic algorithm parameters allow the robots to recharge their batteries autonomously without loss of robots due to insufficient charge. The genetic algorithm is able to optimize collection rates while also dealing with relatively high system error due to inexpensive and sub-optimal sensors onboard the robots. The distributed nature of the robotic swarm prevents a single point of failure and allows the system to operate even with the loss of one or more robots.

Off-planet applications of such a system include water-ice detection and



Two Swarmie robots are shown here searching for resources, or bar codes. NASA photo.

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mining, terrain mapping and habitat construction in advance of human explorers. Terrestrial applications include search-and-rescue, hazardous waste cleanup, land mine removal and infrastructure inspection and repair. The approach used in the software could also be adapted to search the Internet or to search large unknown data sets.

This project has helped demonstrate that in an obstacle laden environment, trails used as a simple indirect communication strategy can allow a swarm of small, low-cost robots to collect resources in an optimal manner when coupled with a genetic algorithm to evolve behaviors. This project has also helped demonstrate that an autonomous robot swarm can evolve battery charging behavior using a genetic algorithm to minimize or eliminate dead robots due to insufficient charge.

The project has been successful in meeting the original goals in simulated field trials and also in real robots. The genetic algorithm is able to evolve optimal behaviors allowing for efficient resource collection while coping with various obstacle arrangements and resource distributions. The genetic algorithm is also able to maintain a high level of fitness while incorporating autonomous recharging of the robots. It has also been demonstrated that this system is error tolerant, adaptable to different robot types, and is scalable in both environment size and numbers of robots.

All of these robot behaviors are performed in real-time with a small, low-cost onboard computer and small memory footprint. The robot platform is constructed using commercial off-the-shelf parts and 3D printed parts with a total cost of less than \$1,500 per robot.

A secondary goal of this project was to extend the genetic algorithm to other new and commercially available robot platforms. Another secondary goal was to use open source software frameworks to help reduce barriers and allow future researchers to more easily utilize genetic algorithms for behavior evolution in a swarm of robots. The project has been successful in meeting both of these secondary goals.

This autonomous mobile robot system is a foundation for future research into the suitability of robot swarms and evolutionary algorithms for in-situ resource utilization missions. The low-cost of this type of system removes one of the barriers typically associated with swarm operation and research. Such research should prove valuable as humans explore harsh, remote, or inaccessible locations where teleoperation is required.

## Anticipated Benefits

This research area provides several possible benefits to NASA's Science

## Organizational Responsibility

### Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

### Lead Center / Facility:

Kennedy Space Center (KSC)

### Responsible Program:

Center Innovation Fund: KSC CIF

## Project Management

### Program Director:

Michael R Lapointe

### Program Manager:

Barbara L Brown

### Project Manager:

Kurt W Leucht

### Principal Investigator:

Kurt W Leucht

### Co-Investigator:

Karl Stolleis

## Technology Areas

### Primary:

- TX17 Guidance, Navigation, and Control (GN&C)
  - └ TX17.1 Guidance and Targeting Algorithms

*Continued on following page.*

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Technology Mission Directorate (STMD) Game Changing Development (GCD) Human Robotic System (HRS) projects such as Regolith Advanced Surface Systems Operations Robot (RASSOR) 2 which is under development at KSC's Swamp Works. Off-planet applications of such a system include water-ice detection and mining, terrain mapping and habitat construction in advance of human explorers. The confirmation of the viable concept of operations along with the proof of concepts for autonomous navigation, path planning, and power management could improve performance and reliability of in-situ robotic mining agents such as RASSOR2. The development environment, including the simulation verification environment, along with the low cost robotic platforms reduce the cost of design and development of software for these types of applications.

This research provides potential benefit to any unfunded & planned NASA missions such as OxMiner or an Asteroid Retrieval Mission engaged in in-situ resource mining. Off-planet applications of such a system include water-ice detection and mining, terrain mapping and habitat construction in advance of human explorers. The confirmation of the viable concept of operations along with the proof of concepts for the autonomous navigation, path planning, and power management improves performance and reliability of in-situ robotic mining agents. The development environment, including the simulation verification environment, along with the low cost robotic platforms reduce the cost of design and development of software for these types of applications.

This research provides potential benefit to the commercial space industry commercial asteroid mining ventures which are proposed by Planetary Resources, Inc., Deep Space Industries, Inc. Moon Express, Astrobotics, or any entity engaged in in-situ resource location and operations. Off-planet applications of such a system include water-ice detection and mining, terrain mapping and habitat construction in advance of human explorers. The confirmation of the viable concept of operations along with the proof of concepts for the autonomous navigation, path planning, and power management improves performance and reliability of in-situ robotic operations. The development environment, including the simulation verification environment, along with the low cost robotic platforms reduce the cost of design and development of software for these types of applications.

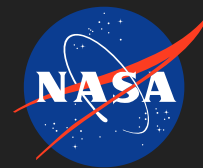
This research provides potential benefit to other government agencies such as the Department of Defense (DOD) or Defense Advanced Research Projects Agency (DARPA) engaged in in-situ resource location and operations. Terrestrial applications include search-and-rescue, hazardous waste cleanup, land mine removal and infrastructure inspection and repair. The approach used in the software could also be adapted to search the Internet or to search large unknown data sets. The confirmation of the viable concept of operations along with the proof of concepts for the autonomous navigation, path planning, and power management improves performance and reliability of

## Technology Areas (cont.)

- └ TX17.1.2 Targeting Algorithms

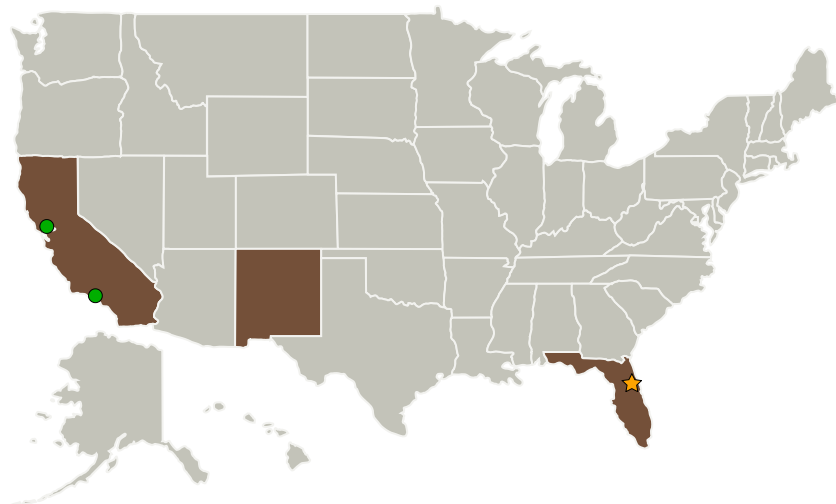
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in-situ robotic operations. The development environment, including the simulation verification environment, along with the low cost robotic platforms reduce the cost of design and development of software for these types of applications.

## Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★ Kennedy Space Center(KSC)	Lead Organization	NASA Center	Kennedy Space Center, Florida
● Ames Research Center(ARC)	Supporting Organization	NASA Center	Moffett Field, California
● Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California

Co-Funding Partners	Type	Location
Biological Computation Laboratory, University of New Mexico	Academia	New Mexico

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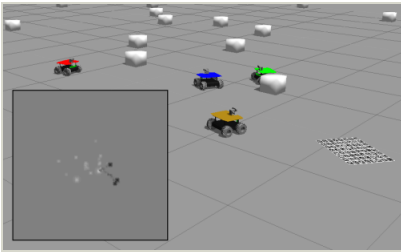
## Primary U.S. Work Locations

California

Florida

New Mexico

## Images



### Computer simulated Swarmie robots

This image shows a computer simulation of a swarm of robots searching for resources, or bar codes, among a field of obstacles. The inlay shows a map containing obstacles in white and found resources in black.

(<https://techport.nasa.gov/image/16317>)



### Swarm of robots searching for resources

This image shows a swarm of four robots searching for resources, or bar codes, in a NASA parking lot. (<https://techport.nasa.gov/image/16319>)



### Swarmie robots

Two Swarmie robots are shown here searching for resources, or bar codes. NASA photo.

(<https://techport.nasa.gov/image/16315>)

## Stories

Discovery News: Swarmie Space Robots Forage Like Ants

(<https://techport.nasa.gov/file/5278>)

Engadget: NASA's Swarmies are a squad of smaller, less intelligent rovers

(<https://techport.nasa.gov/file/5280>)

Evolving Ant-Inspired Search Techniques for a Swarm of Autonomous Robots

(<https://techport.nasa.gov/file/22135>)

Fast Company: These Robots Will Mine Outer Space For Water And Minerals

(<https://techport.nasa.gov/file/5282>)

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IEEE Spectrum: NASA Training Swarmie Robots for Space Mining  
(<https://techport.nasa.gov/file/5277>)

NASA Kennedy YouTube video: Inside KSC! Feb 27, 2015  
(<https://techport.nasa.gov/file/21461>)

NASA Kennedy YouTube video: Swarmies Work Through Field Tests  
(<https://techport.nasa.gov/file/21462>)

NASA Website: Meet The Swarmies - Robotics Answer to Bugs  
(<https://techport.nasa.gov/file/5275>)

NASA Website: Swarmies Shuffle Through Field Tests  
(<https://techport.nasa.gov/file/21459>)

SPACE.com: NASA's Robot Army of Swarmies Could Explore Other Planets  
(<https://techport.nasa.gov/file/5279>)

Spaceport Magazine (cover story): Robots Take World by Swarm  
(<https://techport.nasa.gov/file/5276>)

Spaceport Magazine: Engineers seek more efficient search from Swarmies  
(<https://techport.nasa.gov/file/21460>)

Success Story - Swarmathon  
(<https://techport.nasa.gov/file/26336>)

WOFL FOX 35 Orlando (video segment): NASA programming robots to act like ants  
(<https://techport.nasa.gov/file/5281>)

## Links

KSC-13987  
(no url provided)